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## **Bridging the Gap between In- and Out-of-Hospital Care: the Role and Limitations of Technology**

**Stacy A. Shackelford, Colonel, USAF, Medical Corps**

22 South Greene St, Rm T4M14

Baltimore, MD 21201

UNITED STATES

Tel: 001-410-328-6873, Fax: 001-410-328-7549

stacy.shackelford@us.af.mil

### **ABSTRACT**

*Our system of trauma care in the military is compartmentalized, with various roles of care linked together by transport teams. The gap between in- and out-of-hospital care occurs because we train separately, we communicate only briefly at the time of handoff, and the pre-hospital providers rarely receive followup on their care.*

*In order to bridge the gap, we must work together through improved communication, training, and data collection to define specific components of advanced trauma care that can be moved closer to the point of injury.*

- *Even successful interventions available on the battlefield today need improvement*
- *Technology needs to be integrated with medical and tactical training*
- *We must develop the science of training*
- *The best medicine on the battlefield is firepower—the medical response must occur within the framework of the tactical mission*

### **1.0 DEFINING THE GAP**

As surgeons we are trained to be self-centered. The realm of saving lives revolves around us. We command a highly trained medical team that quickly responds to our orders. Pre-hospital care is basically getting the patient to the surgeon. Intensive care is what happens in between trips to the operating room.

It took me some time to appreciate the importance of prehospital care, and to understand that trauma patients don't just show up at the hospital where the surgeon can save their life. They arrive at the hospital through a deliberately planned emergency response system that depends on brave and well-trained medics who provide life-saving care under difficult circumstances. A few years ago, my eyes were opened to the spectrum of trauma care when I led the Joint Theater Trauma System team into Afghanistan in 2012. I learned that care of the injured casualty extends from prevention of injury all the way through to rehabilitation. In this vast system, the trauma surgeon is only one link in the chain of survival. Indeed, we are rather useless if not supported by dozens of assistants. We struggle even pick up our own instruments by ourselves.

When I oversaw the trauma system, I realized that our system of care is compartmentalized, various roles of care linked together by transport teams. And this is where I first began to look at what I call the gap between in- and out-of-hospital care. The gap is more than just the location where care is provided. It is the fundamental difference in the way care is delivered. And it is a lack of understanding of one another's environment.

## Bridging the Gap between In- and Out-of-Hospital Care

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In the hospital we have a clean environment, good lighting, and a team of specialists. Resuscitation procedures are performed in parallel, with several caregivers working at the same time, overseen by a surgeon. Imaging and labs give us additional information. We have the capability to open the chest and abdomen and stop bleeding at the source. The complexity of the environment, and perhaps also a large rank difference, may make it unwelcoming for a medic.

In the field, one medic may need to care for several patients at once, exposed to the environment, with only the supplies and equipment carried in their pack. Only one intervention may be performed at a time, and interventions must be prioritized. On the battlefield, the medic's life may be in danger while they work to save the life of another. If the surgeon in the hospital does not appreciate the challenges faced by the medic, the care provided may seem incompetent or incorrect. Or, on the other hand, the surgeon may be concerned of seeming overly critical and thereby fail to provide valuable feedback to the medic that could improve care.

But the real gap occurs, not just because of these differences, but because we train separately, we communicate only briefly at the time of handoff, and the pre-hospital providers rarely receive followup on their care.

A few years ago, I took care of a patient in Bagram, Afghanistan. He arrived from the point of injury with several other patients and was dropped off at the hospital with only a brief report. He had a cricothyroidotomy in place—it was one of the most screwed up cricothyroidotomies I have ever seen. In fact, the incision wasn't even in the midline and the tube wasn't actually in the cricothyroid membrane, but nevertheless the tube was in the airway and the patient was alive. Next I tried to ascertain the indication for cricothyroidotomy; there was no obvious facial trauma. In fact, there was no other mark on his entire body, no other injury, just a screwed up cricothyroidotomy. He gets a chest X-ray which shows a bullet in the chest, on CT we see that the bullet is in the left mainstem bronchus. How can we put this story together? Eventually, I decided that the patient had been shot in the trachea and somehow the bullet had remained in the airway and dropped down into the chest; the medic, who may actually have been a genius, cannulated the entry wound with a tracheostomy tube. But I never saw that medic again. I never knew how that patient actually presented on the battlefield, and I never got a chance to tell the medic how the patient did as a result of the care he received.

As surgeons, we understand the physiology of injury better than any other. We see the outcomes of the injury and the outcome of pre-hospital care that was given. We know what needs to be done to save a life. We know the spectrum of care that is possible in an ideal environment, from something as simple as needle decompression to as complicated as ECMO (extracorporeal membrane oxygenation) cannulation. We must work together with the prehospital providers to discover what is possible in their environment so that gradually more advanced care is pushed farther forward. And that is what I mean by bridging the gap between in- and out-of-hospital care—*working together through improved communication, training, and data collection to define specific components of advanced trauma care that can be moved closer to the point of injury.*

## 2.0 A DECADE OF TACTICAL COMBAT CASUALTY CARE

As we have strived to save more lives on the battlefield, we have improved Tactical Combat Casualty Care. Our top advances over the past decade, although supported by a great deal of research, are essentially low tech. On the 10<sup>th</sup> anniversary of the Committee on Tactical Combat Casualty Care, as described by CAPT Butler and COL Blackbourne in 2012,<sup>1</sup> the top 20 advances in Battlefield Trauma Care 2011 included:

1. Phased care: care under fire, tactical field care, tactical evacuation care

2. Aggressive use of tourniquets
3. Combat gauze
4. Nasopharyngeal airways
5. Sit up, lean forward for maxillofacial trauma
6. Aggressive use of needle thoracostomy
7. De-emphasis on spinal precautions
8. IV access only when required
9. Preferential use of saline lock over running fluids
10. Intraosseus access
11. Hypotensive resuscitation with Hextend
12. Oxygen use for TBI
13. More rapid and effective battlefield analgesia
14. Prevention of hypothermia, hypothermia management kits
15. Battlefield use of antibiotics to reduce infections
16. Tactical scenario-based combat trauma training
17. Use of 1:1 plasma and PRBC for casualties in shock during TACEVAC
18. Better definition of benefit of supplemental O2 during TACEVAC
19. Use of TXA
20. Use of Combat Ready Clamp to control junctional hemorrhage

The top 20 advances in pre-hospital care. None of these life-saving advances on the battlefield can really be described as “high tech.” No electronics. No moving parts. Just simple effective devices and an organized systematic method of training.

### **3.0 RESEARCH PRIORITIES**

In the US military, research priorities are identified by what we call a “gap analysis”. The gap analyses can occur at many levels, but essentially represents an opportunity for operational teams to identify gaps in their current capabilities that could be addressed by future research or procurement. In 2012, the top 10 research priorities in Tactical Combat Casualty Care, as released by the Defense Health Board (DHB),<sup>2</sup> included:

1. Unit based prehospital trauma registries
2. FDA-approved freeze-dried blood products (such as plasma and platelets)
3. Clinicopathological review of every U.S. combat fatality, including preventable death analyses from combat units
4. Development and testing of non-compressible torso and junctional hemorrhage control devices
5. Optimized airway devices and training
6. Optimal fluid resuscitation for casualties with TBI and shock
7. Training and evaluation methods for TCCC skills
8. Impact of TCCC interventions in preventing PTSD and TBI, including the role of analgesia in preventing PTSD
9. Combat casualty care monitoring devices
10. Impact of TACEVAC provider level and skill sets on survival (prospective studies)

The research priorities that were listed by the DHB focused on improved devices and pre-hospital data and outcomes collection, an area that has lagged behind in-hospital data collection through the trauma registries. In the area of pre-hospital care “we don’t know what we don’t know” and improved data collection is essential.

Again, in our research priorities, we do not see an emphasis on advanced technological solutions. A

notable exception is combat casualty care monitoring devices, an identified need for a technologically advanced solution to monitoring in tactical combat casualty care.

## **4.0 DEFINING TECHNOLOGY**

It is easier to think of examples of technology than to come up with a definition of technology. The most useful definition I have found comes from an author by the name of Emmanuel Mesthene who was the director of the Harvard University Program on Technology and Science in 1970. In his book “Technological change: its impact on man and society,” he defined technology as “the organization of knowledge for practical purposes.”<sup>3</sup> Dr. Mesthene argued that technology is simply an extension of human capabilities, and advocated for a moderate approach to incorporating technological advances into society. Today, most of us think of technology in the form of electronics, computers, or automation. Is there a role for high technology on the battlefield?

I’d like to share two quotes that I think of in regard to technology.

*1. If I’d asked customers what they wanted, they would have said "a faster horse".*  
-Henry Ford (Founder of Ford Motor Company)

Some technology may be so far beyond our current means that it is difficult for the user to even conceive of what the future may hold in terms of technology. Is it possible that an advanced researcher can develop a new concept that will carry us into a new era previously unimagined? This is the world of science fiction: the handheld “tricorder” from Star Trek that creates a high definition scan of the entire body to diagnose disease and injury; the autonomous critical care transporter that will go out onto the battlefield and scoop up casualties and initiate stabilization procedures, or even farther in the future, place the body in some type of suspended animation.

*2. Everything is very simple in War, but the simplest thing is difficult. These difficulties accumulate and produce a friction which no man can imagine exactly who has not seen War.*  
-Clausewitz, 1827

A word of caution. Clausewitz reminds us that we must focus on simple solutions. What has saved the most lives? The tourniquet. Although seemingly simple, placing a tourniquet is difficult, especially when a life depends on it, especially under fire. Can we make a better tourniquet?

## **5.0 ON THE CUTTING EDGE**

In the past few years, a lot of attention has focused on improved treatments for bleeding, and rightfully so, considering that about 90 percent of prehospital deaths are caused by hemorrhage.<sup>4</sup> We have implemented prehospital blood transfusion onto our MEDEVACS; freeze dried plasma has become more widely available outside of the United States; TXA is working its way closer to the point of injury; and several models of the junctional tourniquets are being put into use with a number of case reports filtering back demonstrating some success with these new devices.

All of these prehospital interventions are presently lacking in outcomes data, and still demand a great deal of research attention going forward. While many of these interventions already have a strong evidence base for in-hospital care, we still need to define the indications and risks in the prehospital environment.

What is the role of ultrasound on the battlefield? Can we diagnose pneumothorax, identify torso hemorrhage? Physicians and advanced medics are increasingly looking at ways to integrate ultrasound diagnosis into prehospital care, perhaps guiding triage or the need for chest decompression, or in the not-

too-distant future, guiding the placement of resuscitative endovascular balloon occlusion of the aorta or expanding intrabdominal foam to control abdominal and pelvic hemorrhage.

Helmet and body blast sensors are capable of measuring the forces transmitted to a soldier's body during an explosion. Two models of sensors have already been deployed with U.S. Army units, and some preliminary data obtained. If the blast sensor data can be correlated with clinical outcomes, this may provide valuable information on blast exposure and injury. It may be possible to immediately clear a soldier to return to duty or identify those at risk for severe injury based on direct measurements of the blast pressure.

In spite of recent advances, we still have a great need for improved products and devices. Up to 83% of tourniquets applied in combat do not occlude the arterial pulse.<sup>5</sup> Battlefield cricothyroidotomy has a 33% failure rate.<sup>6</sup> Needle decompression of the chest may fail in up to 58% of cases.<sup>7</sup> As a trauma surgeon, I have utilized just about every topical hemostatic agent on the market today, and I am still waiting for the material that will reliably stop bleeding when the patient is truly bleeding to death. We can do better.

## **6.0 FUTURE CONCEPTS**

What does the future hold for technological advances in Tactical Combat Casualty Care? As researchers, we are paving the road to the future of battlefield medicine.

**Situational awareness.** We currently have blue force tracking technology that allows us to use global positioning satellites to identify friendly forces and dramatically reduce the incidence of friendly fire incidents. I believe one day it will be possible to achieve a much higher level of situational awareness in regard to casualties, to use sensors to measure the force of a blast and to measure the degree of hemorrhagic shock and brain injury, to transmit this information to a central location, and to control the medical response side by side with the battle captain.

**Decision support.** This is the concept that we can use sensors to help assess a casualty, to analyze vital signs and vital sign waveforms, possibly even point of care laboratory results, and synthesize all available information to create a clinical assessment to help identify compensated shock, early respiratory deterioration, or intracerebral hemorrhage. Such sensors could improve the accuracy of triage and prioritize the MEDEVAC response, identify casualties needing immediate blood transfusion or chest decompression, or identify casualties who need direct transport to neurosurgery. Decision support is already in use for fluid management in burn resuscitation. Such technology may be of value to augment the assessment skills of prehospital providers. Decision support must be based on analysis of thousands of patients and must be reliable. It is unlikely that decision support will achieve 100 percent accuracy and must not become a replacement for training and judgment, however decision support has great potential to improve care of the wounded.

**Autonomous care.** This is care that can be delivered by a machine, replacing the need for human training and decision-making. The most promising possibility under investigation currently is an autonomously controlled ventilator, able to sense pulmonary compliance, oxygenation, and end tidal CO<sub>2</sub> in order to deliver the appropriate tidal volume, respiratory rate, and inhaled oxygen content. Other possibilities in the future include autonomous control of fluids and even vasopressors, sedation, and pain medication. This has great potential for benefit and also great potential for harm, and will require an extensive basis of evidence to support such technology.

After 14 years of war in Afghanistan, let us not become entrenched in the trauma system that we set up there. We need to shift our focus to future worldwide scenarios that may require us to respond with prolonged field care, mobile surgical support, and prolonged evacuation without the benefit of a robust



role 3 hospital.

## **7.0 TRAINING AND TECHNOLOGY**

Some technological solutions can replace the need for additional training (decision support, autonomous ventilators). Other solutions create an additional training burden for the prehospital provider (blood product transfusion, ultrasound, REBOA, intra-abdominal foam, junctional tourniquets). Even improved devices will require further training to implement properly. The problem that we face is that there is never enough opportunity for training. The training that is received does not fully replicate real world events. Experience is better than training, but comes only with time and with mistakes made.

Coming back to my preferred definition of technology: “the organization of knowledge for practical purposes.” I believe that our human brain is the ultimate technology on the battlefield, and our efforts to advance casualty care should refocus on fine-tuning our medics, assembling knowledge, and refining technology as an extension of the human capability. How can we take medical training to the next level? How can we approach training from a research perspective? Can we analyze our training outcomes? Quantify skill? Develop better training methods? How do we sustain training? These are gaps in our knowledge that we have barely begun to investigate.

In my group at the University of Maryland, we have a research team that is focusing on the investigation of trauma surgical skills. Although other investigators have examined surgical skills related to other specialties, to my knowledge this is the first group to formally define critical skills for trauma surgeons and to develop a method for evaluating a surgeon’s skills and defining expertise. With this method, we can then measure the effect of training on the surgeon’s skill and the effect of time since training on skill degradation. There are, however, a lot of intangibles that we have not begun to measure; how does an effective leader function in a stressful environment, and what are the specific skills of an effective surgical leader?

I challenge the research community to bring this type of investigation to the out-of-hospital providers. Let us formally define the skillset of the battlefield medic and the flight medic. Once the critical skills are defined, bring together a group of recognized expert medics and measure their performance of these critical skills using clear outcome measures—this will define a standard of expertise. Quantify the effects of training. Compare training methods. Measure skill degradation after training and define the necessary training intervals. Now is the time to begin—our medics have gained incredible experience over the past 14 years. We need to capture that experience and pass it on.

## **8.0 CONCLUSION**

Even successful interventions available today are still in need of improvement. In the near future, we will probably save more lives by making a better tourniquet and increasing tourniquet training. We have to date not implemented a single advanced technology or electronic device into widespread use in tactical combat casualty care. It remains to be proven whether this is even possible. Our challenge in the long run is to bring advanced technological solutions that are rugged, reliable, and consistently available. The technology needs to be integrated with both medical and tactical training.

At the same time, we need develop the science of training. We must define expertise and train experts. New technologies need to be integrated with training.

As we develop the individual technologies that can be pieced together to create a larger system of casualty care, we need to work together. We must seek guidance not only from our medical leaders, but also from our combatant commanders. We must never forget that the best medicine on the battlefield is firepower

and the enemy has a say in our medical response. Any medical response needs to occur within the framework of the tactical mission.

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